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H01L 41/08

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H1E EB ED

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GB 2252869 A

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UK CL (Edition K) H1E EB ED EF
INT CL[5] H01L

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(54) Laminated electro-mechanical transducer element

(57) A laminated displacement transducer element formed by alternately laminating a plurality of thin sheets made of an electro-mechanical transducer material 1, 2 and a plurality of internal electrodes made of an electrical conductive material 3, 4. External terminals made of an electrical conductive material are connected to the side edges of alternate internal electrodes, and the side edges of the alternate internal electrodes protrude from the side edges of the thin sheets. The protruded portions are formed into an enlargement 5a, e.g. in cross-sectional a torpedo or mushroom shape, having a thickness larger than the thickness of the internal electrodes. Insulating layers 7 are provided on and in the vicinity of the side edges of other internal electrodes between the protruded portions. Finally external electrodes 9 are provided around the protruded portions and outside the insulating layers.

FIG.18

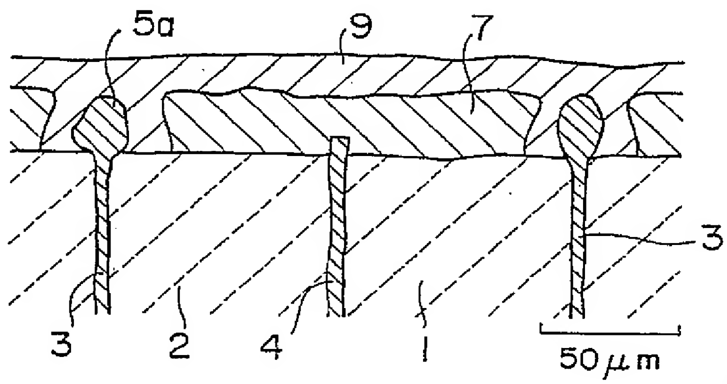

FIG.22

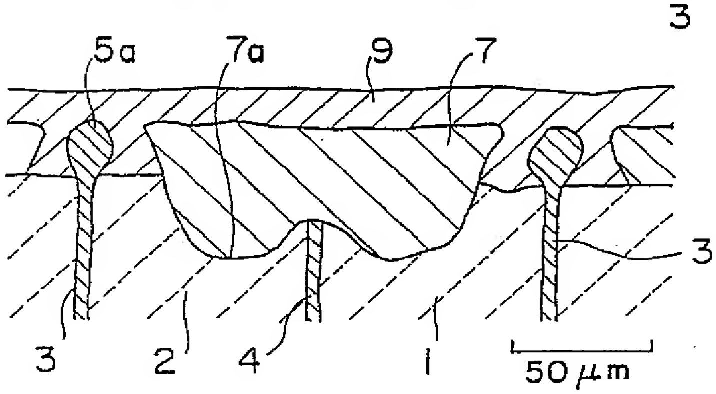

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FIG. 1
(PRIOR ART)

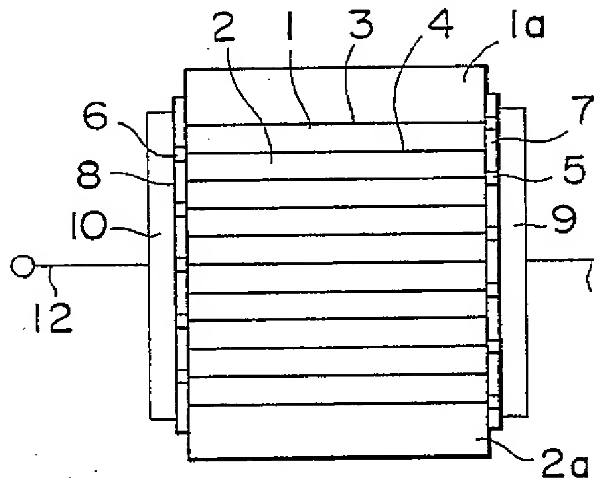


FIG. 2
(PRIOR ART)

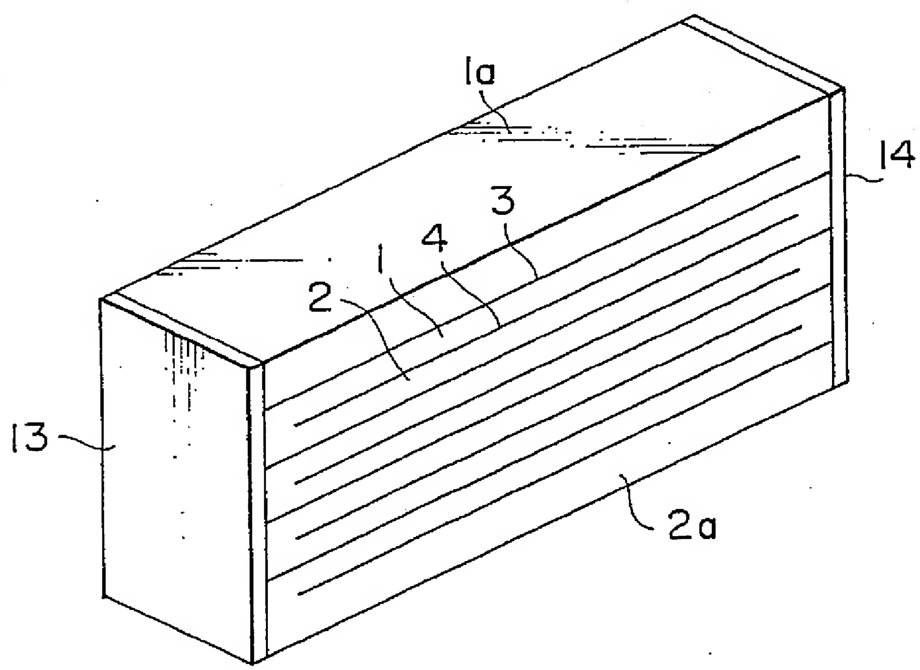


FIG.3
(PRIOR ART)

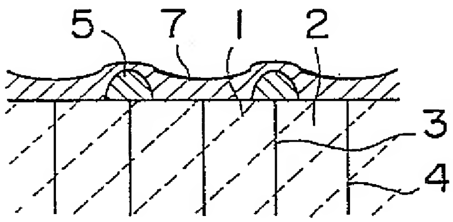


FIG.4
(PRIOR ART)

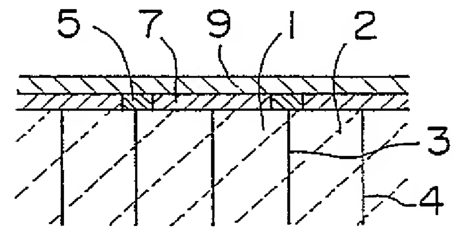


FIG.5
(PRIOR ART)

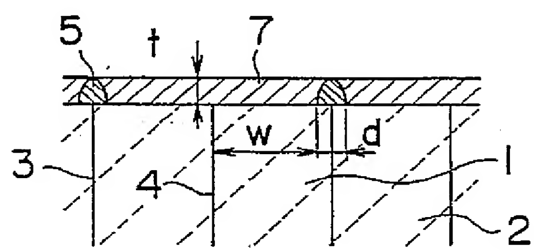


FIG.6
(PRIOR ART)

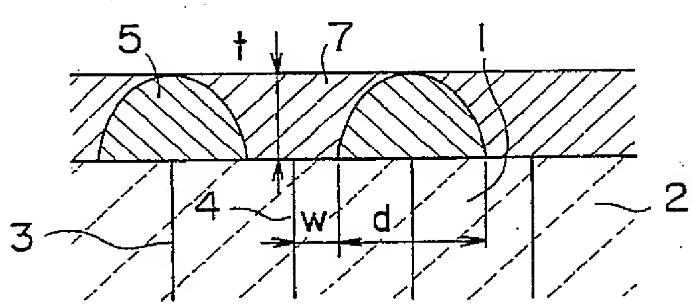


FIG.7

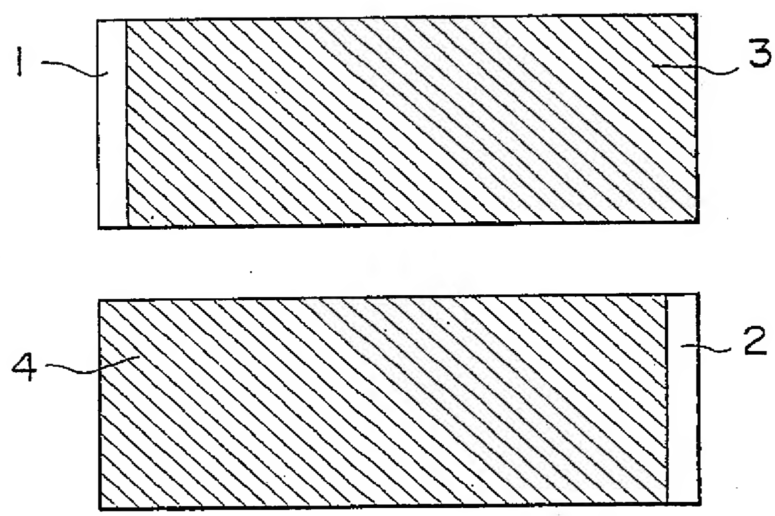


FIG.8

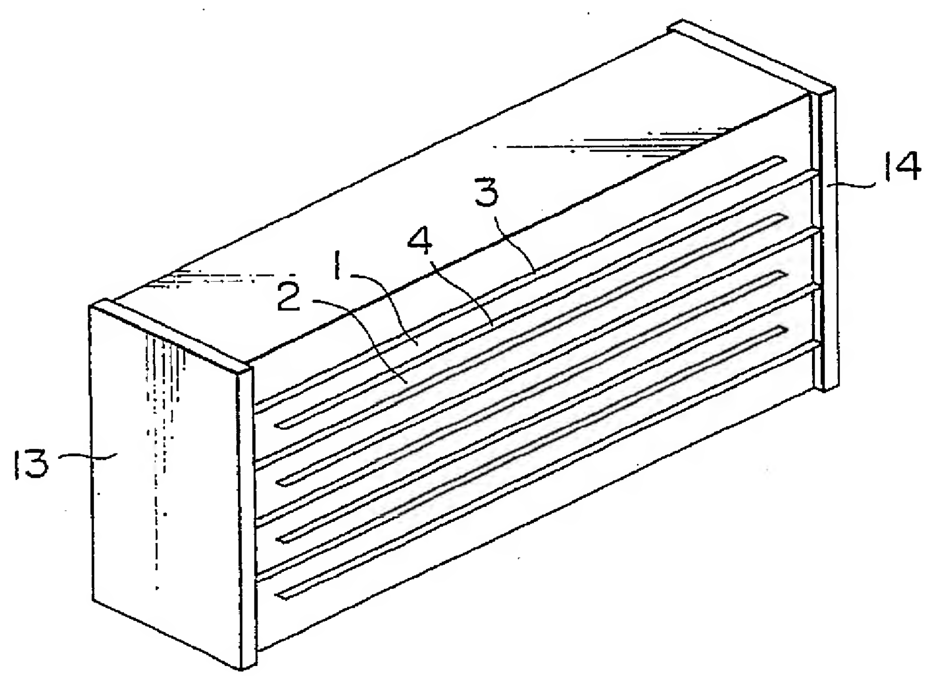


FIG.9

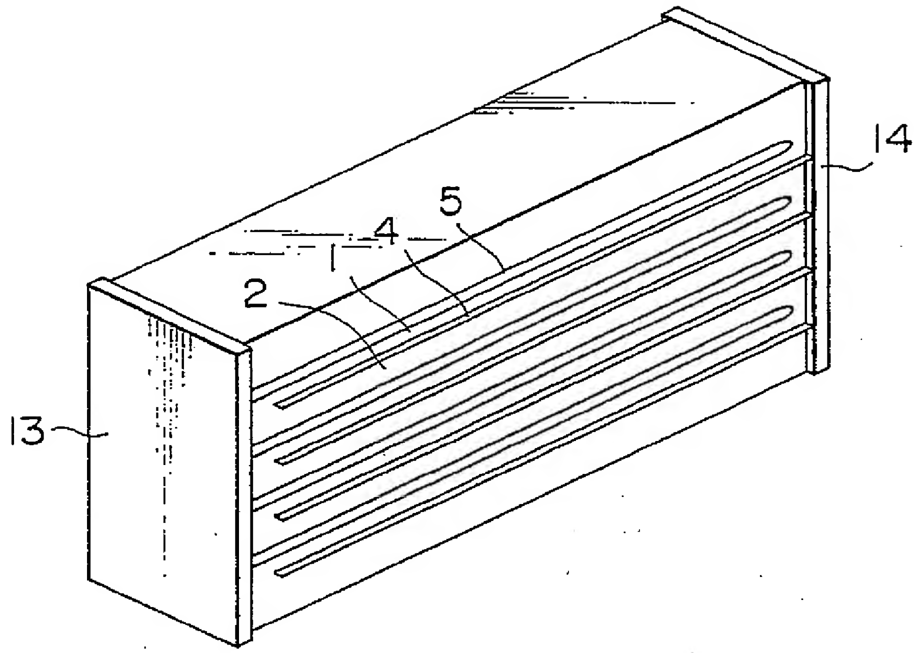


FIG.10

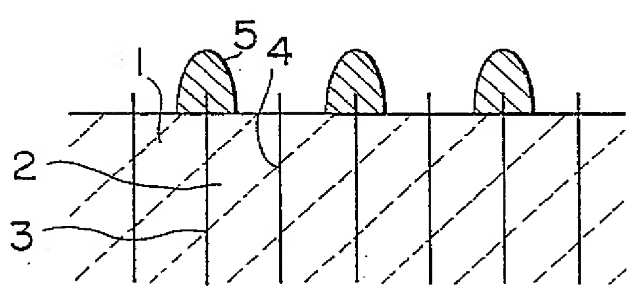


FIG.11

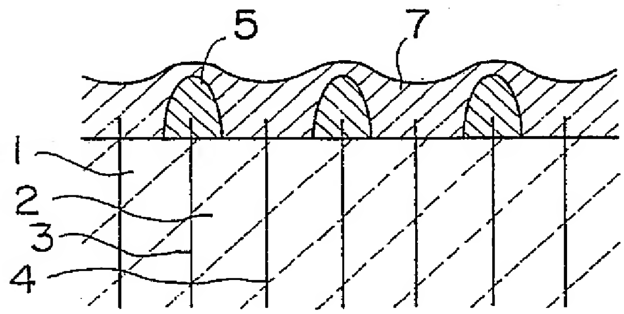


FIG.12

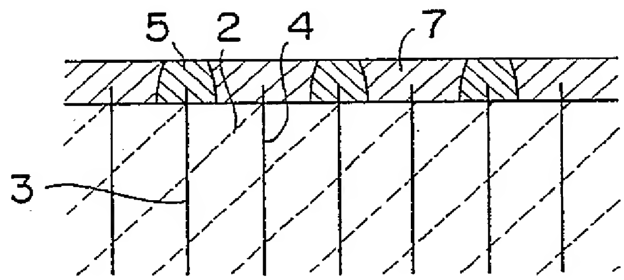


FIG.13

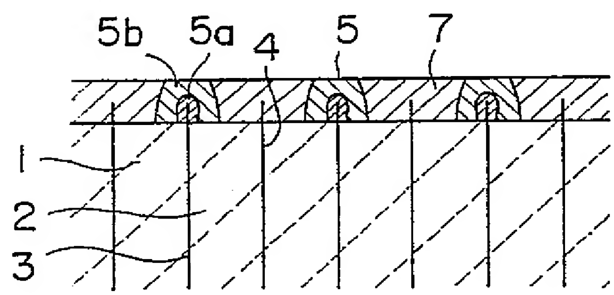


FIG.14

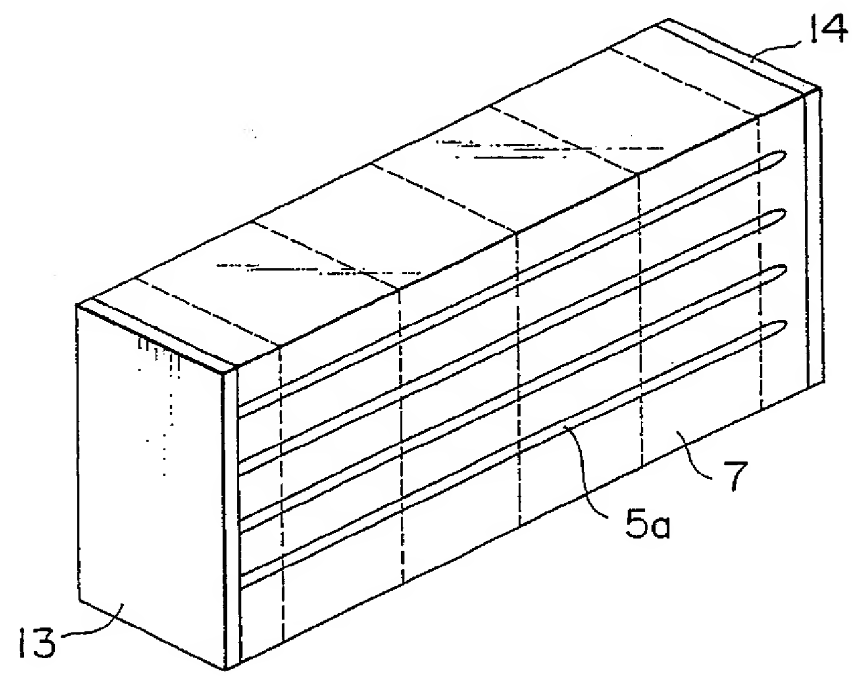


FIG. 15

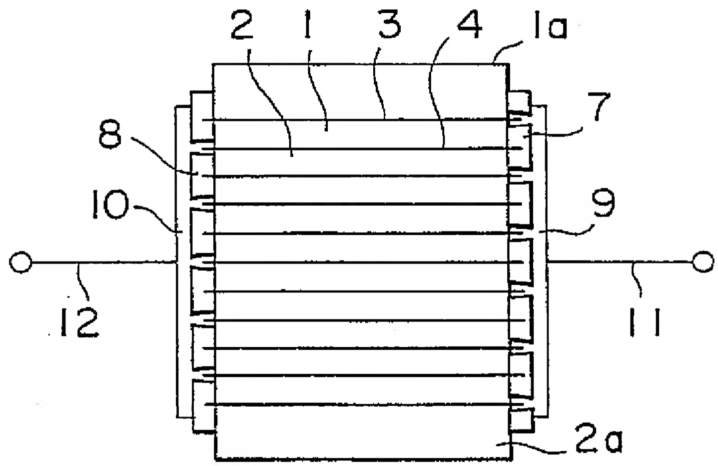


FIG. 16

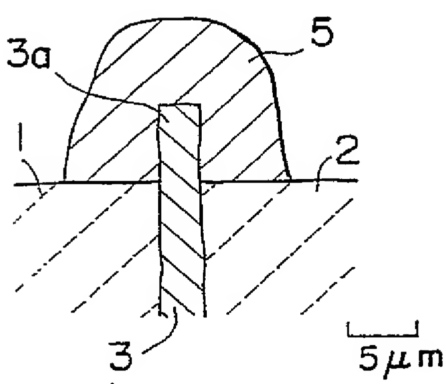


FIG. 17

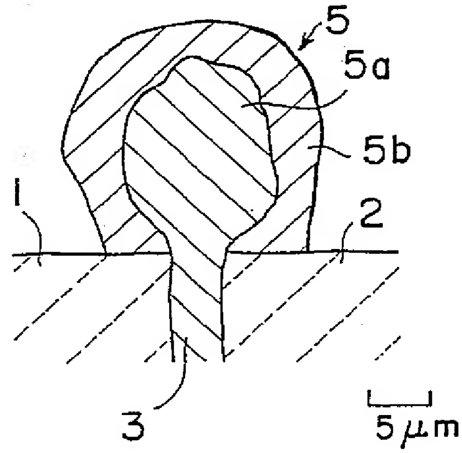


FIG.18

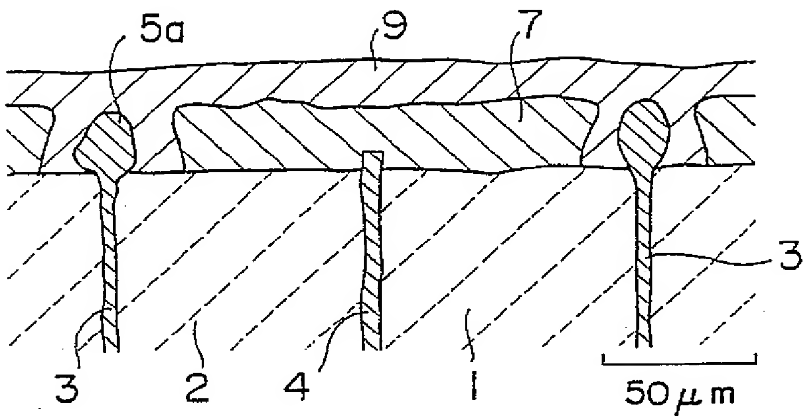


FIG.19

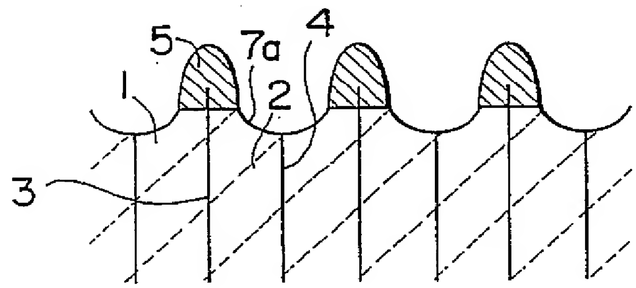


FIG.20

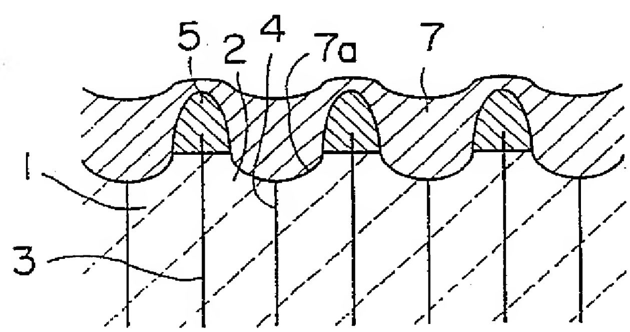


FIG. 21

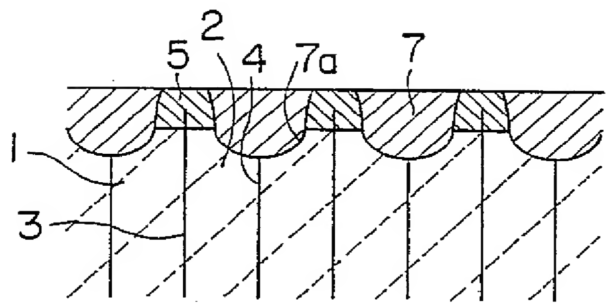


FIG. 22

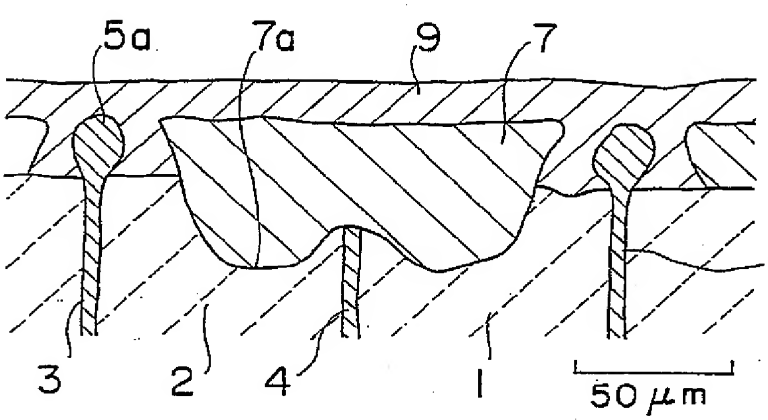
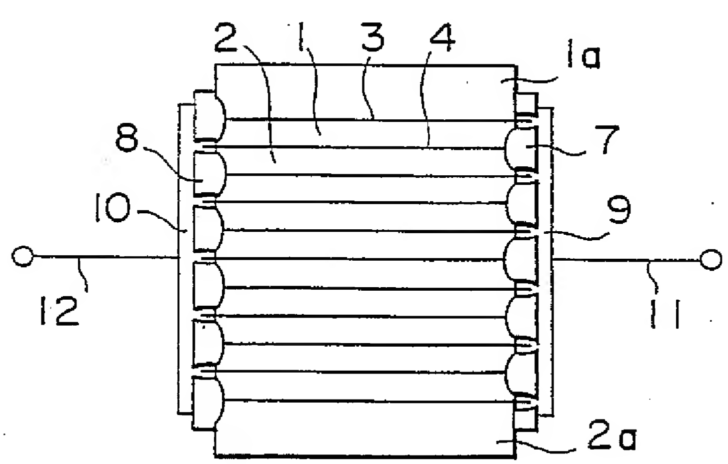


FIG. 23



A LAMINATED DISPLACEMENT TRANSDUCER ELEMENT AND METHOD OF MAKING IT.

This invention relates to a laminated displacement transducer element used as a drive source for actuators in industrial robots, and ultrasonic motors, and a method of making the same. More particularly the invention relates to a laminated displacement transducer element having improved reliability for electrically connecting the side edges of the internal electrodes at the side surface of the laminate to external electrodes.

It is generally believed that the so-called overall type electrode construction of laminated displacement transducer elements relying on the longitudinal electrostrictive effect, which has internal electrodes of the same surface area as the cross-sectional area of the element is effective to prevent stress concentration upon generation of displacement, see Japanese Published Unexamined Patent Specification No. 196068/1983.

In order to obtain large displacement by generating a high electrical field at a low voltage, it is necessary for the spacings between internal electrodes to be less than 100 μm. Special problems arise, however, in electrically connecting in parallel alternate internal electrodes having the same surface area as the cross-sectional area of the element. Thus, drawing out electrodes or lead wires from the ends of alternate internal electrodes is extremely difficult because a laminated displacement transducer

element manufactured by using the method of manufacturing laminated capacitors has spacings of only several tens or several hundreds of micrometers, and the thickness of the internal electrodes exposed to the side surface is only several micrometers.

With a view to solving the aforementioned difficulties, Japanese Published Unexamined Patent Specification No. 196981/1985 and Japanese Published Patent No. 56826/1990 proposed a method of manufacturing a laminated displacement transducer element in which metal is deposited in a strip shape by plating on the side edges of alternate internal electrodes exposed to the side surface of a laminate made of an electro-mechanical transducer material having the aforementioned constructions, external electrodes being connected to the internal electrodes via the metal-deposited areas. There is still, however, problems and the invention has therefore been made with these points in mind.

According to the invention in one aspect there is provided a method of manufacturing a laminated displacement transducer element comprising forms on a laminate of alternate thin sheets of electro-mechanical transducer material and internal electrodes made of an electrically conductive material, with the laminate having two opposing side surfaces on which the side edges of all the internal electrodes are exposed, and having two opposing electrodes on which the side edges of alternate said internal electrodes are exposed. Temporary external electrodes on

the two opposing side surfaces on which the side edges of alternate the internal electrodes are exposed, plating strip-shaped metal deposits integrally with every other internal electrode on the side surfaces on which the side edges of all the internal electrodes are exposed using the temporary external electrodes as the negative electrode, forming insulating layers on the side surfaces on which the strip-shaped metal deposits, and exposing said strip-shaped metal deposits, and forming external electrodes for electrically connecting to the exposed strip-shaped metal deposits, the forming of the insulating layers and/or the external electrodes being affected in a non-oxidizing atmosphere.

According to the invention in another aspect there is provided a method of manufacturing a laminated displacement transducer element comprising forming on a laminate of alternate thin sheets of electro-mechanical transducer material and internal electrodes made of an electrically conductive material, with the laminate having two opposing side surfaces on which the side edges of all the internal electrodes are exposed, having two opposing electrodes on which the side edges of alternate the internal electrodes are exposed, and with the side edges of the internal electrodes protruding from the side edges of the thin sheets, temporary external electrodes on the two opposing side surfaces on which the side edges of alternate said internal electrodes are exposed, plating strip-shaped metal deposits integrally with every other internal electrode on

the side surfaces on which the side edges of all said internal electrodes are exposed using the temporary external electrodes as the negative electrode, forming insulating layers on the side surfaces on which the strip-shaped metal deposits are formed, exposing the strip-shaped metal deposits, and including exposing alloy layers of a material of which internal electrodes are made and the plated metal by removing the plated metal from exposed portions of the strip-shaped metal deposits.

The invention also extends to a laminated displacement transducer element having alternate laminations of a thin sheet of an electro-mechanical transducer material and an internal electrode made of an electrically conductive material, external terminals made of an electrically conductive material connected to the side edges of alternate of the internal electrodes, the side edges of alternate of the internal electrodes protruding from the side edges of the thin sheets of transducer material in such a fashion that the protruding portions are enlarged so having a thickness greater than the thickness of the internal electrodes, insulating layers provided on and in the vicinity of the side edges of other internal electrodes between the protruded portions, and external electrodes around the protruded portions and outside the insulating layers.

The laminated displacement transducer elements of the invention have improved reliability. Also the electrical conductivity between the internal electrodes and the

external electrodes is maintained without producing unwanted oxides on the surface of the strip-shaped metal deposits formed integrally with the internal electrodes exposed to the side surfaces of the laminate.

In one embodiment of the invention the electrical conductivity between the internal electrodes and the external electrodes is maintained by removing plated metal from the exposed area of the strip-shaped metal deposits to prevent the formation of oxide films of the plated metal.

In another embodiment of the invention the thickness of the insulating layers can be increased, and thereby insulation strength can be increased, by removing at least part of the protruding portion of other internal electrodes existing between the strip-shaped metal deposits.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a longitudinal sectional view illustrating the essential part of a laminated displacement transducer element manufactured conventionally;

Figure 2 is a perspective view of another conventional laminated block;

Figures 3 and 4 are longitudinal sectional views illustrating the essential part of a laminate during conventional manufacture;

Figures 5 and 6 are enlarged longitudinal sectional views illustrating the neighbourhood of the

insulating layers of the conventional laminated displacement transducer elements;

Figure 7 is a plan view illustrating the essential part of the thin sheets and the internal electrodes in a transducer element according to the invention;

Figures 8 and 9 are perspective views illustrating the laminated block during the production of the element according to the invention;

Figures 10 to 13 are longitudinal views illustrating the essential part of the laminate of the invention during manufacture;

Figure 14 is a perspective view illustrating the resulting laminated block;

Figure 15 is a longitudinal sectional view illustrating the essential part of the laminated displacement transducer element according to the invention.

Figures 16 and 17 are enlarged longitudinal sectional views illustrating the neighbourhood of the strip-shaped metal deposits in a laminated block of an element according to the invention;

Figure 18 is an enlarged longitudinal sectional view illustrating the stage where an external electrode is deposited;

Figures 19 to 21 are longitudinal sectional views illustrating the essential part of a manufacturing process for making a further element according to the

invention;

Figure 22 is an enlarged longitudinal sectional view illustrating the stage where the external electrode is deposited; and

Figure 23 is a longitudinal sectional view illustrating the further laminated displacement transducer element according to the invention.

Figure 1 is a longitudinal schematic sectional view of assistance in explaining an example of a laminated displacement transducer element manufactured conventionally. Thin sheets of an electro-mechanical transducer material 1 and 2, such as a piezoelectrical ceramic material, are separated by internal electrodes 3 and 4 made of a thin film of electrically conductive material. The electrodes and material 1 and 2 are laminated alternately to form a columnar laminate using the technique to manufacture laminated ceramic capacitors. At top and bottom protective plates 1a and 2a made of the same material as that of the thin sheets 1 and 2, are fixed.

Strip-shaped metal deposits 5 and 6 made of a plated metal, such as nickel are deposited in a strip shape on the side edges of alternate internal electrodes 3 and 4. Insulating layers 7 and 8 are formed between the strip-shaped metal deposits 5 and 5, or 6 and 6. Numerals 9 and 10 refer to external electrodes for electrically connecting a plurality of strip-shaped metal deposits 5 and 6. Lead wires 11 and 12 electrically connect the external electrodes 9 and 10.

Figure 2 is a perspective view illustrating how a laminated block is manufactured conventionally. As shown in Figure 2, the thin sheets 1 and 2, and the internal electrodes 3 and 4 are formed into a rectangular shape, and stacked alternately to form a laminate using laminated ceramic capacitor technology. The side edges of all the internal electrodes 3 and 4 are exposed to two opposing side surfaces constituting the longitudinal outside surfaces (board-side surfaces) of the laminate, while the alternate side edges of the internal electrodes 3 and 4 are exposed to the other facing side surfaces (narrow-side surfaces), respectively. Numerals 13 and 14 refer to temporary external electrodes electrically connected to the side edges of the internal electrodes 3 and 4 that are alternately exposed to the facing narrow-side surfaces.

The laminate shown in Figure 2 and a plating-electrode metal plate (not shown) are immersed in a plating bath of nickel, for example, and as d.c voltage is applied from the plating electrode metal plate to the temporary external electrode 13 or 14, positively charged nickel ions in the plating bath deposit on the external electrode 3 or 4 to form the strip-shaped metal deposits 5 and 6 (refer to Figure 1). Figure 3 shows the strip-shaped metal deposit 5 formed on the side edge of internal electrodes 3.

In Figure 3, an insulating layer 7 is formed on the side surface on which the strip-shaped metal deposit 5 has been formed. To form the insulating layer 7, a paste-like insulating material applied on the side surface is baked.

The surface of the baked insulating layer 7 is then partially removed by polishing to cause the strip-shaped metal deposit 5 to be exposed.

The laminated block formed in this way is cut into multiple pieces along a plane parallel to the side surface of the laminate on which the temporary external electrodes 13 and 14 have been mounted. An external electrode 9 is formed on the side surface to which the strip-shaped metal deposit 5 has been exposed, see Figure 4. Though not shown in Figure 4, an external electrode is also formed on the other opposing side surface. Thus, a laminated displacement transducer element as shown in Figure 1, in which the internal electrodes 3 and 4 are connected alternately can be obtained. When voltage is applied to the external electrodes 9 and 10 via the lead wires 11 and 12, therefore, application of voltage to the internal electrodes 3 and 4 causes the thin sheets 1 and 2 to be displaced to drive the laminated displacement transducer element.

Since electro-mechanical transducer materials are generally sintered in an oxidizing atmosphere, silver/palladium or platinum and other oxidation-resisting previous metals are used as the material for the internal electrodes 3 and 4. As the material for the strip-shaped metal deposits 5 and 6 base metals are used because a metal to be deposited by plating has to be ionized. When the laminated block is placed in a high-temperature environment to form the external electrodes 9 and 10 in the

manufacturing method of laminated displacement transducer elements of the conventional type, the strip-shaped metal deposits 5 and 6 consisting of the above-mentioned deposited metal tend to be oxidized, deteriorating electrical conductivity with the external electrodes 9 and 10. In extreme cases, the volume increase resulting from the oxidation of the strip-shaped metal deposits 5 and 6 causes the strip-shaped metal deposits 5 and 6 to crack, leading to unwanted phenomena, such as the breaking or separation of the strip-shaped metal deposits 5 and from the internal electrodes 3 and 4 and the external electrodes 9 and 10.

To solve these problems, a method of forming the external electrodes 9 and 10 in a reducing atmosphere was tried, but it was found that the thin sheets 1 and 2 made of an electro-mechanical transducer material were also reduced, impairing the properties of the thin sheets 1 and 2 required for a laminated displacement transducer element.

In addition, another possible means for solving the above problems is the use of precious metals as the material for forming the strip-shaped metal deposits 5 and 6. However, the use of silver could lead to lowered insulation resistance due to migration, and the use of platinum or palladium could lead to the attack of the thin sheets 1 and 2 by the plating solution.

Although an organic resin material that is formable at relatively low temperatures can be used as the material for the insulating layers 7 and 8 and/or the external

electrodes 9 and 10, such materials are not suitable because of the degradation of the material after long-term service or due to the presence of water, or lowered mechanical strength in a high-temperature atmosphere.

Another problem is that insulating layers 7 and 8 of a sufficient thickness cannot be obtained because the thickness of the insulating layers 7 and 8 depends on the thickness or height of the strip-shaped metal deposits 5 and 6 formed as the result of metal deposition by plating. Figures 5 and 6 are longitudinal sectional views illustrating the neighbourhood of the insulating layers of the conventional laminated displacement transducer element.

As shown in Figure 5, the thickness of the insulating layer 7 is t whilst, the distance between the strip-shaped metal deposit 5 and the internal electrode 4 having a different electrical polarity is w. The distance w should preferably be larger in terms of insulating performance. When the width d of the strip-shaped metal deposit 5 is reduced to increase the distance d, however, the height of the strip-shaped metal deposit 5 formed by plating is also reduced. Thus, a sufficient thickness t cannot be ensured for the insulating layer 7, leading to lowered insulating resistance.

As shown in Figure 6, on the other hand, deposition of larger strip-shaped metal deposits 5 could increase the width d of the strip-shaped metal deposit 5, and accordingly decrease the distance w between the strip-shaped metal deposit 5 and the internal electrode 4. This

could make it difficult to ensure a sufficient insulating distance or creeping distance. With the aforementioned method, furthermore, the contact area between the strip-shaped metal deposit 5 and the internal electrode 4 (though not shown in the figure, the same applies to the strip-shaped metal deposit 6 and the internal electrode 3 as shown in Figure 1) becomes extremely small. This leads to separation during manufacturing processes due to reduced bonding strength.

A means for solving these problems has been proposed in which the thin sheets 1 and 2 constituting the laminate are etched to cause the side edges of the internal electrodes 3 and 4 to protrude, see Japanese Published Unexamined Patent Specification No. 300577/1989. With this means, electrical contact between the temporary external electrodes 13 and 14 and the internal electrodes 3 and 4 as shown in Figure 2 can be improved, the plated metal is securely bonded to the internal electrodes 3 and 4, the strip-shaped metal deposits 5 and 6 are prevented from separating, and the thickness t of the insulating layer 7 as shown in Figures 5 and 6 can be increased.

Even with the aforementioned means, however, when the external electrodes 9 and 10 as shown in figures 1 and 4 are formed in the atmosphere, there is a problem of failure to ensure electrical conductivity between the strip-shaped metal deposits 5 and 6 and the external electrodes 13 and 14 because the strip-shaped deposits 5 and 6 are oxidized. The protruded length of the internal electrodes 3 and 4,

whose thickness is as small as 3 to 5 μm, is limited as such; too long a protruded length of the internal electrodes 3 and 4 may result in the collapse, deformation, etc. of the protruded portion, unwantedly reducing the distance w between the adjoining internal electrodes 3 and 4 having a different polarity. Moreover, too long a protruded length of the internal electrodes 3 and 4 could prolong the etching time of the thin sheets 1 and 2, leading to lowered productivity and the reduced effective area of the thin sheets 1 and 2 that can contribute to strain generation.

Figures 7 to 14 are diagrams illustrating the manufacture of a first embodiment of the transducer element according to the invention. Like parts are indicated by like numerals used in Figure 1 to 6.

PVB as an organic binder, BPBG as a plasticizer, and trichlene (tricholoroethylene) as an organic solvent are added to powders of electro-mechanical transducer materials chiefly consisting of $Pb(Zr, Ti)O_3$-$Pb(Mg, Nb)O_3$, and mixed to form a slurry. The slurry formed is fed on a Mylar (RTM) film (polyethylene-glycol-terephthalate film) with the doctor blade process to form a sheet of a thickness of 100 μm. The resulting sheet is then separated from the Mylar film. As shown in Figure 7, a paste consisting of silver-palladium or platium is printed on one side of the thin sheet 1 to form an internal electrode 3 or 4. In Figure 7, the internal electrode 3 is omitted on the left edge of the thin sheet 1, while the internal electrode 4 is omitted on

the right edge of the thin sheet 2.

Several dozens of the thin sheets 1 and 2 shown in Figure 7 are alternately laminated and press-bonded at elevated temperatures, subjected to the binder removal treatment and, sintered at 1100 to 1250 °C for 1 to 5 hours to prepare a laminated block on both end faces of which the internal electrodes 3 and 4 are exposed alternately, as shown in Figure 2. Temporary external electrodes 13 and 14 are provided on both end faces of the laminated block.

After the upper and lower surfaces, to which the temporary external electrodes 13 and 14 and the internal electrodes 3 and 4 are not exposed, are masked, the laminated block is etched to cause the side edges of the internal electrodes 3 and 4 to protrude, as shown in Figure 8. That is, the side edges of the internal electrodes 3 and 4 can be caused to protrude by 10 μm by etching the side edges of the thin sheets 1 and 2 by immersing for 60 minutes the laminated block in a 10%-chloric acid solution held at 50 °C.

After the etching treatment described above, any one of the side surfaces of the laminated block which have been subjected to the etching treatment is masked with a masking agent to subject the opposite surfaces to the plating treatment. The laminated block and the plating electrode (not shown), made of nickel, are immersed in a plating solution of 300g of nickel sulphate, 45g of nickel chloride and 45g of boric acid in 1 litre of pure water, and a d.c. voltage is applied across the temporary external electrode

13, as shown in Figure 9, as the negative electrode and the plating electrode (not shown) as the positive electrode at a current density of 40A/dm^2 for 20 minutes. As a result, strip-shaped metal deposits 5 having a height of 50 μm and a thickness of 40 μm are deposited on the side edges of the internal electrodes 3, for example, as shown in Figures 9 and 10. Next, strip-shaped metal deposits are deposited on the side surfaces which have been masked with a means similar to that described above. That is, strip-shaped metal deposits similar to the strip-shaped metal deposit 5 are also deposited on the side edges of the internal electrodes 4 on the other side surface of the laminated block.

Next, an insulating layer 7 is formed on the side surfaces of the laminated block on which the strip-shaped metal deposits 5 are deposited by applying a paste consisting of an insulating material, such as glass powder, to the side surfaces and baking the coated paste, as shown in Figure 11. The same applies to the other opposing side surfaces of the laminated block. The strip-shaped metal deposits 5 are partially exposed by lapping the surface of the insulating layer 7 as shown in Figure 12. The same applies to the other opposing side surfaces. The laminated block is then immersed in a 10%-nickel chloride solution, and subjected to the electrolytic etching treatment by applying d.c. voltage across the temporary external electrodes 13 and 14 as the positive electrode and the plating nickel electrode as the negative electrode at a

current density of 40A/dm^2 for 30 minutes. With this electrolytic etching treatment, only alloy layers 5a (an alloy of the internal electrode material and nickel) constituting the strip-shaped metal deposits 5 are left unetched with the nickel layers 5b deposited around the alloy layers 5a removed. The same applies to the other opposing side surfaces.

The laminated block thus obtained is cut along the broken lines shown in Figure 14 into a plurality of single elements. By attaching external electrodes to the single element, a laminated displacement transducer element is obtained. Figure 15 is a longitudinal sectional view illustrating a completed laminated displacement transducer element. By applying a paste consisting of an electrically conductive material to the side surfaces of the laminate and baking the coated paste, the external electrodes 9 and 10 are tightly bonded to the strip-shaped metal deposits 5 consisting of the alloy layer 5a in such a fashion as to wrap the alloy layer 5a, and thus connected to the corresponding internal electrodes 3 and 4.

Figures 16 and 17 are enlarged longitudinal sectional views illustrating an area close to the strip-shaped metal deposits 5. In Figure 16, the strip-shaped metal deposit 5 is tightly bonded by plating to the surrounding area of the protruded portion 3a of the internal electrode 3 (corresponding to Figure 10, above). When an insulating layer 7 is formed on the strip-shaped metal deposits 5, as shown in Figure 11, the protruded portion 3a forms an alloy

layer 5a and expands into a torpedo or mushroom shape thicker than the thickness of the internal electrode 3 in cross section during baking treatment, as shown in Figure 17. Numeral 5b in the figure denotes a nickel layer forming an outer shell of the alloy layer 5a.

Since the strip-shaped metal deposits 5 are formed in the aforementioned fashion, the nickel layer 5b forming an outer shell is removed by electrolytic etching, as shown in Figure 13, and the alloy layer 5a which is difficult to oxidize by metallic nickel is left. Therefore, when an external electrode (not shown) is formed around the alloy layer 5a, the external electrode has good resistance to breaking or separation by an external force because of mechanical anchoring, in addition to the increased contact area between both. Figure 18 is an enlarged longitudinal sectional view showing the external electrode deposited. As the alloy layer 5a has oxidation-resisting characteristics, unwanted oxide layers are hard to form on the alloy layer 5a even if the baking of the external electrode 9 is performed in the atmosphere. However it is recommended that the baking of the external electrode 9 should be carried out in a non-oxidizing atmosphere, such as argon or nitrogen gas.

Figure 19 to 21 are longitudinal sectional views illustrating part of a process for manufacturing a second embodiment of transducer element according to the invention. Like parts are indicated by like numerals used in Figures 10 to 13.

Figure 19 is a diagram illustrating the stage where part off the component material between the strip-shaped metal deposits 5 is removed. That is, after the strip-shaped metal deposits 5 have been formed, grooves 7a are formed by shot blasting. Thus, by blowing a stream of abrasive powder, such as alumina, silicon carbide or silicon dioxide, the internal electrodes 4, and the side edges of the thin sheets 1 and 2 around the internal electrodes 4, on which no strip-shaped metal deposits 5 are formed, are selectively removed to form the grooves 7a. By shot blasting abrasive powder of #400 alumina for 10 seconds, grooves 7a of about 20 μm in depth are formed. The method of forming the grooves 7a is not limited to shot blasting.

Next, an insulating layer 7, as shown in Figure 20, is formed, and the strip-shaped metal deposits 5 are partially exposed by lapping the surface of the insulating layer 7, as shown in Figure 21. The same proceeding is applied to the opposing surfaces.

The resulting laminated displacement transducer element as shown in Figure 23 can be eventually obtained by following the processes similar to those shown in Figures 13 to 15. In the laminated displacement transducer element thus formed, dielectric strength can be improved because the distance along the groove 7a between the strip-shaped metal deposits 5 and the internal electrodes 4 having a different polarity from that of the strip-shaped metal deposits 5 (interface distance or creeping distance, the

distance w in Figures 5 and 6) can be substantially increased, and the thickness of the insulating layer 7 can also be increased, as is apparent from Figures 19 to 21.

Figure 22 is an enlarged longitudinal sectional view illustrating the stage where the external electrode is deposited, corresponding to Figure 18. As is evident from Figure 22, the external electrode 9 is found deposited in such a manner as to wrap the alloy layer 5a constituting the strip-shaped metal deposit 5. Furthermore, the thickness of the insulating layer 7 is increased due to the formation of the groove 7a, resulting in the increased interface distance or creeping distance between the internal electrodes 3 and 4.

In Figures 19 to 21, the grooves 7a of a circular arc shape in cross section are formed between the strip-shaped metal deposits 5 and 5, at least part of the protruded portion of the internal electrode 4 may be removed by controlling the speed of the shot blasting.

In view of the fact that nickel as the plated metal is apt to be oxidized among the materials constituting the strip-shaped metal deposits 5 and 6, only after the strip-shaped metal deposits 5 are formed and the insulating layers 7 and 8 are deposited, is the nickel layer remove by electrolytic etching treatment to ensure electrical connection between the internal electrodes 3 and 4 and the external electrodes 9 and 10. It is considered, however, that even when a material that is apt to be oxidized, such as nickel, is left on the strip-shaped metal deposits 5 and

6, electrical connection between the internal electrodes 3 and 4 and the external electrodes 9 and 10 could be ensured if arrangement is made to prevent the material from being oxidized during the baking treatment performed to form the insulating layers 7 and 8 and/or the external electrodes 9 and 10.

A third embodiment according to the invention will be described in the following, referring to Figures 2 to 4. The manufacturing process described was followed except that insulating layer 7 as shown in Figure 3 was formed by baking the insulating paste in an argon atmosphere. Also the external electrode 9 as shown in Figure 4 was formed by baking the electrically conductive paste in an argon atmosphere. After the insulating layer 7 and the external electrode 9 were formed, the portions in question were examined for fracture test. The fracture test results revealed that no oxide layers were found on the surface of the strip-shaped metal deposits 5. When the insulating layer 7 and the external electrode 9 were formed in the atmosphere as in the prior art, on the other hand, oxide layers were formed on the surface of the strip-shaped metal deposits 5 and 6, as noted earlier.

Next, properties of laminated displacement transducer elements manufactured with the prior art and the technology of this invention are shown in the table below. In the table, Test Nos. 1 to 6 represent the embodiments of this invention and No. 7 that of the prior art. In the atmosphere column in the table given are the atmosphere

conditions used in forming the insulating layers 7 and 8, and the external electrodes 9 and 10.

No.	Configu-ration (Figure)	Atmosphere		Electrostatic capacity μF at 1 kHz	Displace-ment μm at 150 V
		Insulating layer	External electrode		
1	15	Air	Air	0.400	8.8
2	15	Argon	Argon	0.482	10.6
3	23	Air	Air	0.418	9.2
4	23	Argon	Argon	0.503	11.2
5	1	Argon	Argon	0.495	10.8
6	1	Air	Argon	0.457	9.6
7	1	Air	Air	0.145	3.2

As is apparent from the table above, test result 7 with the prior art method indicate that the property values remained at low levels because the nickel remaining on the strip-shaped metal deposits 5 was oxidized during baking treatment and there were some internal electrodes 3 and 4 that were not connected to the external electrodes 9 and 10. By contrast the test results 1 to 4 with the method of this invention reveal that the property values were extremely high because the nickel other than the nickel alloy layers constituting the strip-shaped metal deposits 5 and 6 were positively removed. In the argon atmosphere, the property values were further improved. Thus in Tests 5 and 6, nickel remained in the strip-shaped metal deposits 5 and 6, but the property values were found improved because nickel was prevented from being oxidized due to the baking treatment of the insulating layers 7 and 8 and the external electrodes 9 and 10 in the argon atmosphere. In Test No. 6 where the insulating

layers 7 and 8 were baked in the atmosphere, the property values only deteriorated slightly. This is attributable to the fact that when the strip-shaped metal deposits 5 and 6 composed of nickel

were partially exposed by lapping the surfaces of the insulating layers 7 and 8, part of the nickel oxide layer formed at the time of the formation of the insulating layers 7 and 8 was also removed.

In the above described embodiments, nickel is used as the metallic material for the strip-shaped metal deposits 5 and 6. The other metallic materials such as copper, iron, chromium, tin can be used, as can any other metallic material so long as it is electroplatable and can form a plating solution that does not attack the thin sheets 1 and 2 made of an electro-mechanical transducer material. Moreover, an acid solution has been used to cause the internal electrodes 3 and 4 to protrude, but ion etching and any other means can be used so long as they can selectively etch the thin sheets 1 and 2 composed of an electro-mechanical transducer material. Furthermore, the means for removing plated metal around the strip-shaped metal deposits 5 and 6 is not limited to electrolytic etching, but chemical etching using an acid solution, ion etching or any other means may be used.

Transducer elements formed according to the invention have; inter alia, the following advantages:

(1) Since only the plated metal that is apt to be oxidized can be selectively removed from among those

materials constituting the strip-shaped metal deposit, leaving a hard-to-oxidize alloy layer, imperfect electrical connection due to the oxidation of the plated metal and/or mechanical breakage, can be prevented.

(2) Since bulged projections consisting of alloy layers thicker than the thickness of the internal electrodes are formed, the bonding area with the external electrodes can be increased, leading to improved bonding strength.

(3) Insulating reliability can be improved since the interface distance between the thin sheets and the insulating layers or creeping distance between the strip-shaped metals deposits and the internal electrodes having a different polarity can be substantially increased, and the thickness of the insulating layers can be increased.

CLAIMS:

1. A laminated displacement transducer element having alternate laminations of a thin sheet of an electro-mechanical transducer material and an internal electrode made of an electrically conductive material, external terminals made of an electrically conductive material connected to the side edges of alternate of the internal electrodes, the side edges of alternate of the internal electrodes protruding from the side edges of the thin sheets of transducer material in such a fashion that the protruding portions are enlarged so having a thickness greater than the thickness of the internal electrodes, insulating layers provided on and in the vicinity of the side edges of other internal electrodes between the protruded portions, and external electrodes around the protruded portions and outside the insulating layers.

2. An element as claimed in Claim 1 in which the enlarged protruding portion have a torpedo or mushroom shape in cross section.

3. A laminated displacement transducer element substantially as herein described with reference to Figures 7 to 18, or Figures 19 to 23, of the accompanying drawings.

4. A method of manufacturing a laminated displacement transducer element comprising forms on a laminate of alternate thin sheets of electro-mechanical transducer material and internal electrodes made of an electrically conductive material, with the laminate having two opposing side surfaces on which the side edges of all the internal

electrodes are exposed, and having two opposing electrodes on which the side edges of alternate said internal electrodes are exposed; temporary external electrodes on the two opposing side surfaces on which the side edges of alternate the internal electrodes are exposed, plating strip-shaped metal deposits integrally with every other internal electrode on the side surfaces on which the side edges of all the internal electrodes are exposed using the temporary external electrodes as the negative electrode, forming insulating layers on the side surfaces on which the strip-shaped metal deposits, exposing said strip-shaped metal deposits, and forming external electrodes for electrically connecting to the exposed strip-shaped metal deposits, the forming of the insulating layers and/or the external electrodes being affected in a non-oxidizing atmosphere.

5. A method of manufacturing a laminated displacement transducer element comprising forming on a laminate of alternate thin sheets of electro-mechanical transducer material and internal electrodes made of an electrically conductive material, with the laminate having two opposing side surfaces on which the side edges of all the internal electrodes are exposed, having two opposing electrodes on which the side edges of alternate the internal electrodes are exposed, and with the side edges of the internal electrodes protruding from the side edges of the temporary external electrodes on the two opposing side surfaces on which the side edges of alternate said internal electrodes

are exposed, plating strip-shaped metal deposits integrally with every other internal electrode on the side surfaces on which the side edges of all said internal electrodes are exposed using the temporary external electrodes as the negative electrodes, forming insulating layers on the side surfaces on which the strip-shaped metal deposits are formed, exposing the strip-shaped metal deposits including exposing alloy layers of a material of which internal electrodes are made and the plated metal by removing the plated metal from exposed portions of the strip-shaped metal deposits, and forming external electrodes for electrically connecting to the exposed strip-shaped metal deposits.

6. A method as claimed in Claim 5 in which the forming the insulating layers and/or the external electrodes are affected in a non-oxidizing atmosphere.

7. A method as claimed in any of Claims 4 to 6 in which after the strip-shaped metal deposits have been formed, removing at least part of the protruding portions of the other internal electrodes existing between strip-shaped metal deposits.

8. A method of manufacturing a laminated displacement transducer element, substantially as herein described with reference to Figures 7 to 18 or Figures 19 to 23, of the accompanying drawings, or with reference to any of Test Nos 1 to 6 of the Tests.

9. A laminated displacement transducer element when made by a method as claimed in any of Claims 4 to 8.

27.

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(ii) Int Cl (Edition 5) H01L

Databases (see over)

(i) UK Patent Office

(ii)

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Documents considered relevant following a search in respect of claims 1-9

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X,E	GB 2252869 A (HITACHI) 19 August 1992 Whole document	1, 4, 5 at least

SF2(p)

HD - doc99\fil000352

Category	Identity of document and relevant passages	Relevant to claim(s)

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